Il Colle di Galileo

Penetrating the dust in nearby galaxies

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Abstract. New observing facilities have made possible a complete inventory of the components of the interstellar medium (ISM) in galaxies, permitting an enhanced understanding of the ISM energy budget and star-formation processes. To study the ISM in galaxies, an international consortium, KINGFISH (Key Insights into Nearby Galaxies: Far-Infrared Survey with Herschel), met in October, 2012, at the Villa Il Gioiello. There they discussed progress in the ongoing analysis of their dataset, obtained with Herschel, the infrared satellite of the the European Space Agency.

Keywords. Galaxies, star formation, interstellar medium, dust, gas, Herschel, infrared observations.

Systems of stars organized into galaxies such as our own Milky Way are largely empty. Stars and their planetary systems occupy roughly 0.9999999997 of the available volume in a galaxy; however, this volume is partly filled up by the interstellar medium (ISM), that is the gas and dust between the stars. Dark clouds in the Milky Way show that dust in the ISM obscures diffuse starlight, and young regions undergoing violent star formation episodes tend to be surrounded by dust cocoons mixed with gas. Thus, dust provides a key to star formation processes in galaxies, but its emission cannot be easily observed from the ground.

Over the last 30 years, a series of astronomical satellites has been aimed at penetrating dust in the ISM of galaxies and studying it directly through its radiation in the infrared (IR). The most recent of these satellites, the European Space Agency IR facility, *Herschel Space Observatory,* was launched in May, 2009 and exhausted its helium coolant in April, 2013. Of the many observing programs approved for execution with *Herschel*, scientists from the Arcetri Observatory participate in one of the largest, the KINGFISH project. Led by Rob Kennicutt of the Institute of Astronomy, Cambridge, UK, and Daniela Calzetti of the University of Massachusetts, USA, KINGFISH (Key Insights on Nearby Galaxies: a Far-Infrared Survey with *Herschel,* http://www.ast.cam.ac.uk/research/kingfish)

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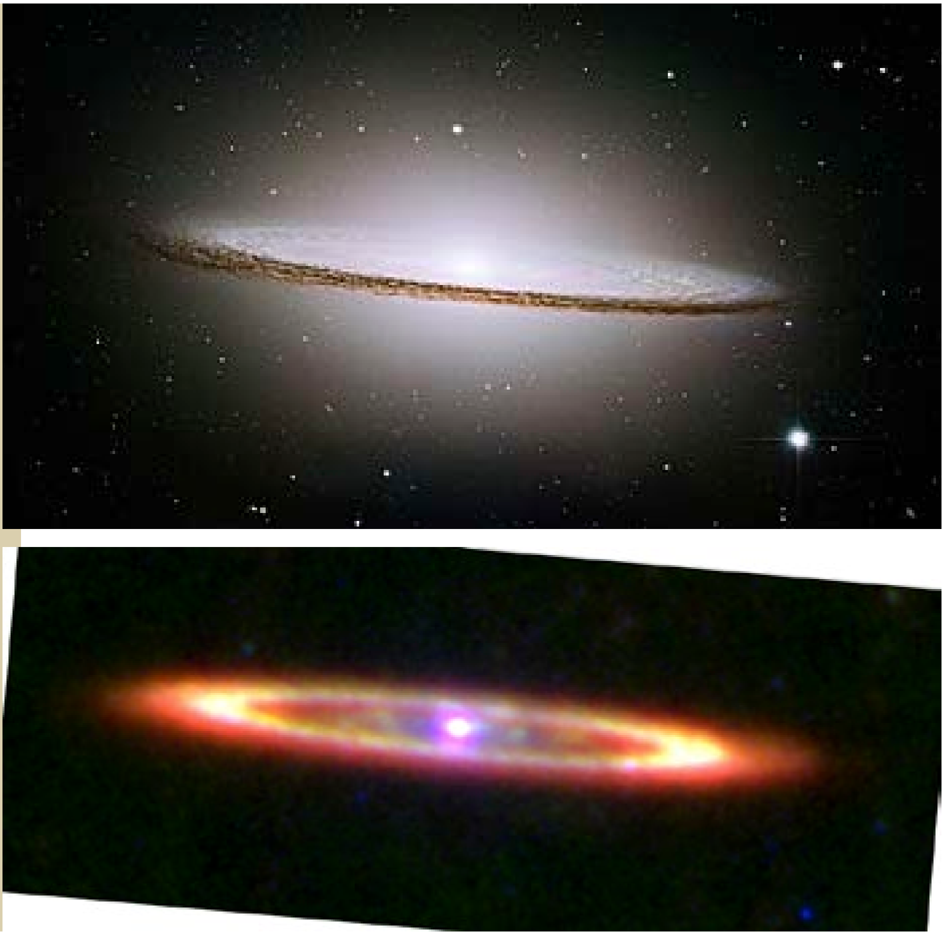


Fig. 1a (top panel). Hubble Space Telescope image of NGC 4594, the Sombrero galaxy. Fig. 1b (low panel). Spitzer+Herschel composite image of the same galaxy (24μm=blue; 100μm=green; 250μm=red). The dark dust lane in the optical shines bright in the IR, and the predominantly red color shows that the dust is quite cool, emitting more at 250μm than at shorter wavelengths.

is an imaging and spectroscopic survey of 61 galaxies. The KINGFISH consortium now consists of more than 60 members; Leslie Hunt is a KINGFISH science coordinator and co-organizer of the meeting along with Stefano Zibetti, also of the Arcetri Observatory.

The KINGFISH project targets nearby galaxies, namely those within 10 million light years from the Earth. The galaxies were chosen to cover a wide range of luminosity, star-formation rate, and ISM properties, in order to be representative of conditions in the Local Universe; many of the targets are spiral galaxies, similar in size and morphology to the Milky Way. The imaging and spectroscopic capabilities of *Herschel* enable an "inventory" of the energy budget of the

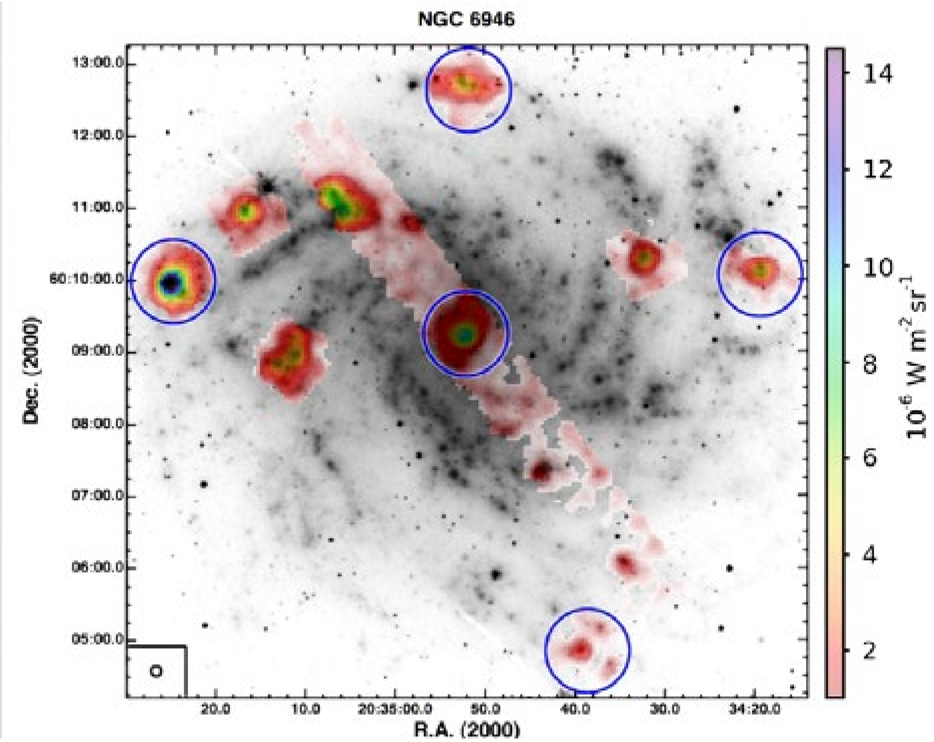
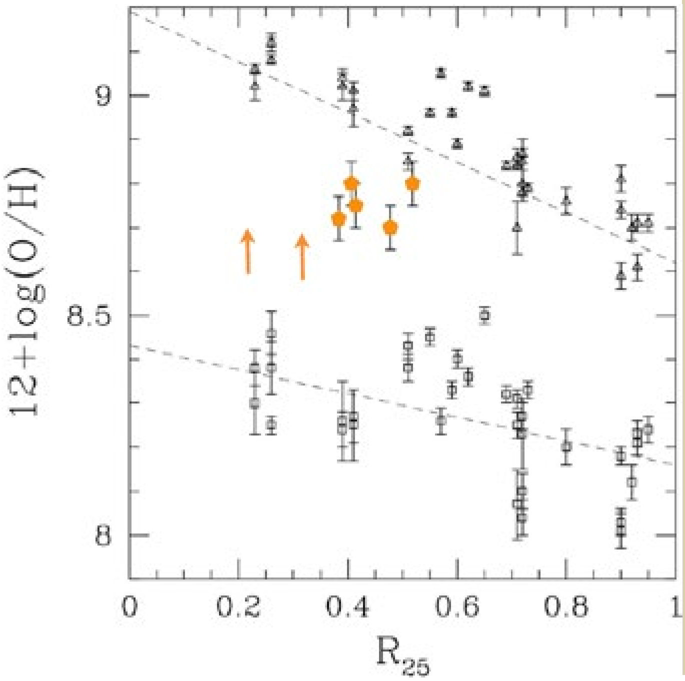


Fig. 2a (top panel). NGC 6946 with ISO 70 arcsec beams (blue circles) and PACS [OIII] 88μm emission in 8 arcsec spaxels (spectroscopic pixels shown in color) overlaid on Spitzer images (3.6μm, 24μm). Fig. 2b (right panel). Previous (optical) oxygen abundance measurements in NGC 6946 based on two different absolute calibrations plotted against R_{25}, the distance from the center of the galaxy relative to the optical radius. There is a clear gradient in the abundance estimates, with the outer portion of the galaxy having a lower abundance than the inner parts. The new 88μm measurements are shown as mustard-colored data points and suggest that one of the two previous abundance calibrations may be incorrect.



ISM, namely how gas and dust emit and absorb radiation, and how these processes are influenced by the birth of new stars and the heating from stars that were formed 10 billion years ago when the galaxy was young. The *Herschel* imaging consists of complete maps for the galaxies at 70, 100, 160, 250, 350, and 500 μm, and spectral line maps of the principal ISM atomic cooling lines ([OI]63μm, [OIII]88μm, [NII]122,205 μm, and [CII]158 μm). The KINGFISH scientific strategy is built around three main objectives: 1) a comprehensive study of the dust-obscured component of star formation in galaxies, and the relation between star formation and dust heating; 2) a complete inventory of cold dust and its relation to other dust components in the ISM; 3) spatially resolved studies of the heating and cooling of the ISM, as traced by atomic cooling lines and the dust. These objectives are now possible thanks to *Herschel*'s superior sensitivity, spectral coverage, and excellent imaging resolution. It is between 5 and 20 times more sensitive than previous satellites, with a spatial resolution 4-6 times better. Its wavelength coverage is unprecedented, since to date there have been virtually no observations of galaxies between 250μm and 500μm. Figure 1 illustrates how thermal imaging with *Herschel* penetrates dust in galaxies: the dark dust lane in the Sombrero galaxy is brightly illuminated at IR wavelengths.

One of the main science highlights presented at the Gioiello workshop concerns far-infrared determinations of chemical abundance. The [OIII] 88μm line measured with the PACS instrument on board *Herschel* is a temperature-insensitive tracer of chemical composition in the ISM. Chemical abundance is an important diagnostic for a galaxy's evolutionary phase, and for the stage of mass assembly in the early universe and nearby. Because IR wavelengths are relatively insensitive to dust obscuration, *Herschel* measurements can help disentangle different abundance calibrations based on optical estimates. Figure 2 shows preliminary results from KINGFISH that illustrate the power of IR spectroscopy in this respect (taken from Croxall et al., 2013, in preparation).